GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3347 GTRI/~~GIT~~ DATE 9/23/82

Project Director: J. D. Walton ~~School~~/Lab EMSL

Sponsor: Raytheon Company
Bedford, MA 01730

Type Agreement: P. O. No. 71-8200BD97000

Award Period: From 8/26/82 To 10/1/82 (Performance) ______ (Reports)

Sponsor Amount: Total Estimated: $ 1,500 Funded: $ 1,500

Cost Sharing Amount: $ NA Cost Sharing No: ______

Title: Engineering Services for Patriot Radome Assembly

ADMINISTRATIVE DATA

OCA Contact Linda H. Bowman x4820

1) Sponsor Technical Contact:

Mr. Ernest Williamson
Raytheon - Mail Stop M27-5
Missile Systems Division
Hartwell Road
Bedford, MA 01730

2) Sponsor Admin/Contractual Matters:

Mr. Richard A. Bishop
Raytheon Company
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Hartwell Road
Bedford, MA 01730
(617) 274-7100

Defense Priority Rating: none

Military Security Classification: none
(or) Company/Industrial Proprietary: none

RESTRICTIONS

See Attached na Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with na

COMMENTS:

COPIES TO:

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Research Security Services
Reports Coordinator (OCA)
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Research Communications (2)
Project File
Other ______
Other ______

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

2-SR-321

Date 9/30/82

Project Title: Engineering Services for PATRIOT Radome Assembly

Project No: A-3347

Project Director: J. D. Walton

Sponsor: Raytheon

Effective Termination Date: 10/1/82

Clearance of Accounting Charges: ____________

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice ~~and Closing Documents~~
- [ ] Final Fiscal Report
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____________

Assigned to: EML (~~School~~/Laboratory)

COPIES TO:

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Research Property Management
Accounting
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Computer Input
Project File
Other ____________

FORM OCA 10:781

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

September 14, 1982

Mr. Bruce Center
DD2-18
Raytheon
Hartwell Road
Bedford, MASS. 01730

Dear Bruce:

It was a pleasure to meet you last week and to become better acquainted with the Patriot radome program. I was impressed with what you have done and was gratified to see an application where slip-cast fused silica has satisfied an important radome need.

I appreciate the chance to see what you have done in tracking down the source of a serious problem which has handicapped your efforts to develop a second source. However, I believe that as a result of your meeting we have begun to narrow down the apparent source of the problem to residual stress in the radome. Now if we can confirm that residual stress is the problem and identify the source of that stress there would be little difficulty in coming up with a solution.

To follow up on my participation in the meeting I have enclosed my report summarizing my impressions of what occurred at the meeting and concluding with recommendations for additional work which should reveal any residual tensile stresses at the interior surface of failed radomes and hopefully identify the source of those stresses. These efforts would concentrate studying failed radome parts containing the attachment ring and are based on George Quinn's observation that he noted a significant residual stress which was manifested by the tendency of the part to close when it was sawn through. After you have had a chance to look this over I would welcome any questions, comments or suggestions you might have.

I will be on vacation during 18-26 September, and will be in the office this week only on Friday, 17 September.

Sincerely,

Jesse D. Walton, Jr.
Energy & Materials Sciences
Laboratory

JDW/gg
Enclosure

Report: Summary and Recommendations Concerning PATRIOT Radome 2nd Source Qualification Test and Evaluation Efforts

By: J. D. Walton, Jr.

Date: 14 September 1982

Reference: Contract No. 1996

I. INTRODUCTION

During 8 and 9 September 1982 a briefing was held at Raytheon to review efforts to qualify a second source of Patriot radome billets. This meeting covered (1) Radome Design and Loads, (2) Qualification Requirements, (3) Brunswick Qualification Summary, (4) Harbison-Walker Qualification Summary, and (5) Failure Analyses, Data Summaries. The meeting concentrated on the failure of three Harbison-Walker radomes to meet the specified failure bending load at a temperature of -30^{O}F.

Physical and mechanical property data were reviewed which indicated that there was no apparent difference between the basic sintered fused silica provided by the two vendors. This led to a discussion of the different processes used in forming, firing and machining the billets and identification of possible sources of residual stresses in the Harbison-Walker billets which might be responsible for the premature failure at -30^{O}F.

II. SUMMARY

As part of the qualification process, finished test radomes are subjected to a mechanical bending test to simulate maneuvering. Test radomes are tested to failure at room temperature, 130^{O}F and -30^{O}F. Under all three conditions the radome failure load must exceed 1.25 times the maximum worst-case maneuvering load. Up to the present time only three Harbison-Walker radomes have qualified, two at room temperature and one at +130^{O}F. Of three radomes tested at -30^{O}F only one reached 100 percent of the design load, the other two reached only 65 and 95 percent. The primary purpose of this meeting was to review all of the supporting test data and try to determine why these radomes failed, and what differences there might be between the Brunswick billets (all of which passed) and the Harbison-Walker billets.

Review of all of the mechanical property data obtained from test samples machined from the various Brunswick and Harbison-Walker radome billets, as well as finished, failed radomes, indicated that there was no apparent difference in the basic material supplied by the two vendors. Detailed review of the test procedure and equipment used turned up no significant difference between the tests conducted on the Brunswick domes (carried out some years ago) and tests conducted on the Harbision-Walker domes during the past two years.

After eliminating the basic material and the test conditions as the source of the problem, attention was turned to differences in the processing and initial grinding of the billets. Harbison-Walker forms their fused silica shape by the electrophoretic deposition of fused silica particles (in a slip-like suspension) onto a graphite mandrel. After the desired thickness is reached (about 1 inch) the mandrel is withdrawn from the slip and the casting is removed from the mandrel almost immediately. The principal advantages of the Harbison-Walker casting are: (1) it can be dried in a very short time, about one day, and (2) it has a very high green (unfired) strength; so high in fact that Raytheon at one time considered machining the unfired radome blank. After firing, the surface of the radome is sanded to remove the hard shell. The billet is then impregnated with GE SR-80 resin, cured and shipped to Raytheon.

The Brunswick billet is slip-cast in a plaster mold in the classical manner. However, Because of the thickness of the casting a very long drying cycle is required. It is dried about one week in the mold, then another week under controlled humidity conditions and finally under forced drying conditions for another week. After firing, Brunswick then grinds off excess internal and external material, about 0.100 to 0.200 inches, impregnates with SR-80 resin, cures and sends to Raytheon. All machining carried out by Raytheon on Brunswick or Harbison-Walker billets is on impregnated material.

In addition to these processing differences, the design of the attachment area of the two billets is different. Since the internal dimensions of the Harbison-Walker billet are determined by the mandrel on which it is formed, it can be cast with internal dimensions near the net value. Therefore, to reduce the amount of machining required in the attachment area, the graphite mandrel was constructed so that it flared outward about 10^{o} at that point. This provided an as-cast taper in the attachment area which matched that of the attachment ring. This modification resulted in a billet on which most of the grinding was done on the outside, a much simpler operation than grinding the inside.

Prior data had shown that the strength of test coupons increased as the distance from the inside surface of the billet increased. This appeared to be due to the increasing cristobalite content with increasing distance from the surface. Typically the cristobalite content reached a constant low value of about 1/2 - 3/4% at a distance of about 15-20 mils from the surface. The strength likewise reached a constant high value as the tensile surface of the flexural specimen reached a distance of the same order of magnitude from the as-cast surface.

With this information we began to consider whether or not residual stresses might be the source of the problem in the Harbison-Walker billet, what processing/material parameters might be responsible for these stresses and why these stresses are not present, or are not a problem in the case of the Brunswick billet.

Two sources of residual stresses were considered: (1) cristobalite and (2) increase in fine particle concentration at the surface in question. In both cases the maximum tensile stress would be on the inside of the radome in the area of the attachment ring.

Examination of scanning electron micrographs of fractured surfaces suggested that the Harbison-Walker product was a finer grain size material than the Brunswick material. However, mocrographs were not made across the entire section to determine whether or not there was an increase in the concentration of fine particles near the interior surface of the billet. Based on strength data mentioned earlier, the strength of the Harbison-Walker material decreased with increasing proximity to the inner surface. Therefore if insufficient material is removed (less than 0.030 inches) in machining the attachment area of the Harbision-Walker billet it would be expected that the interior surface would be weaker than the bulk material and that residual stresses could result because of the presence of cristobalite. If the fine particle concentration is also found to increase near the inner surface additional residual stresses would be expected as a result of differential shrinkage of that area during sintering.

Although a number of modifications to the Harbison-Walker process were suggested as a fix to eliminate the residual stress problem, if that is the problem, they all involved considerable modification of the machining facilities at Raytheon or at Harbison-Walker and would be considered only as a last resort. Therefore the next step suggested was to determine the ovality of the Harbison-Walker billets to establish whether or not there was sufficient material to assure the removal of at least 0.030 inches of material at all stations in the attachment area. Concurrently, the microscopic examination would be made of all failed radomes to determine the concentration of fine particles in the interior and near the exterior surface.

All parties will review the material covered in this meeting and submit additional questions or comments. Based on the results of these efforts a follow-up meeting will be considered at the end of September.

III. CONCLUSIONS

1. The basic sintered fused silica material produced by Harbison-Walker is essentially the same as that produced by Brunswick with respect to fracture toughness, temperature dependency on strength, strain rate, static fatigue, sample oreientation, surface finish and acceptance samples.

2. The Brunswick material is typically stronger than the Harbison-Walker material, although both are well within design specification.

3. Photomicrographs suggested that the particle size of the Harbison-Walker material is typically smaller than the Brunswick material.

4. The Harbison-Walker material contains voids which are not present in the Brunswick material, but these voids were not found to affect the strength of the material.

5. The processes used for forming the fused silica radome blanks are basically different. The Brunswick radome is formed in a female plaster mold by classical slip-casting. The Harbison-Walker is formed on a male graphite mold by electrophoresis.

6. Due to the forming process used, a minimum of material is removed from the interior of the attachment area of the Harbison-Walker billet.

7. Flexural tests of coupons cut from the attachment area show a decrease in strength as the tensile surface of the coupon approaches the as-cast surface of the billet.

8. Available test data and analysis suggest that the cause of the premature failure of the Harbison-Walker radome at -30oF may be due to residual tensile stress at the interior surface in the attachment area.

9. Residual tensile stresses on the interior surface may be due to excessive cristobalite and/or an excess of fine particles with respect to the interior and exterior of the radome.

10. Residual tensile stresses were evidenced in the failed part as manifested by the tendency of the attachment ring/radome base to close when it was cut through during examination of the failed area (AMMRC/George Quinn letter of 17 August 1982).

IV. RECOMMENDATIONS

Based on the results of the briefing at Raytheon and on a subsequent review of the correspondence related to the failure of the Harbison-Walker domes at -30^{O}F, and the conclusions reached, the following additional work is recommended. The results of this effort should aid in determining whether or not excessive residual tensile stresses are present at interior surfaces of the failed Harbison-Walker radome and suggest the source of such stresses.

1. Conduct microscopic examination across the entire cross section of the failed area of Hw 36-104 and 109 to determine homogenity of particle distribution. Concentration of fine particles at the interior surface relative to exterior surface would contribute to development of tensile stresses at the interior surface.

2. Measure or estimate the amount of closure which resulted from cutting through the attachment ring area of the failed part of Patriot Radome HW 36-104. The same should be done for the 36-109. (This assumes that the remaining ceramic is undamaged except for the saw cut.)

3. An attachment ring part from a failed Brunswick radome which passed the -30^{O}F test should be sawn through and the degree of closure (opening) measured.

4. If possible remove the attachment ring from the failed Harbison-Walker radome and determine effect on saw-cut opening/closing.

5. Radome part from 4 should be subjected to -30°F to determine effect of temperature on dimension of saw cut. Repeat at 130°F.

6. Using test temperature of -30°F, repeat test to determine strength variation near casting surface (Memo EAM 81-065, 18 February 1981).